The Mitral Valve Prolapsus : Quantification of the Regurgitation Flow Rate by Experimental Time-Dependant PIV.

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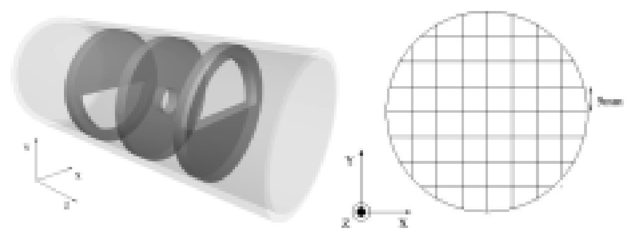
Abstract-**Color Doppler is routinely used for visualisation of intra cardiac flows and quantification of valvular heart disease. Nevertheless the 2D visualisation of a complex 3D phenomenon is the major limitation of this technique. In particular, in clinical setting, the flow rate calculation upstream a regurgitant orifice (i.e. mitral valve insufficiency), assumes that the velocity field in the convergent region have hemispheric shapes and introduce miscalculation specially in case of prolaps regurgitant orifices. The main objective of this study was to characterize the dynamic 3D velocity field of the convergent region upstream a prolaps model of regurgitant orifice based on 2D time dependent PIV reconstruction.**
Keywords-**Mitral Valve, Prolapsus, Regurgitation Flow, PIV.**

I.INTRODUCTION

Color Doppler ultrasound is widely used for the non invasive assessment of valvular regurgitation. The most promising technique for flow calculation, is the two dimentionnal (2D) imaging of the flow convergent field proximal to the orifice. The theoretical background assumes that for a small circular orifice in a flat plane, the flow accelerates toward the orifice and the shapes of isovelocities contours can be represented like hemispheric shells. Besides technical problems (e.e. Color Doppler resolution, angle Doppler effect), the most important limitation of this approach is the geometrical assumption of the proximal isovelocity shape. Futhermore, in clinical setting, the most frequent regurgitant model, is the prolaps one. The flow distribution in this particular case is greatly distributed and the hemispheric model is not valid. Because of inherent problems of 2D representation of complex velocity fields, the 3D approach has been recently proposed. Different 3D ultrasound reconstruction techniques have been described in the literature. The main objective of our study was to characterize the dynamic 3D flow behaviour in a mitral prolaps model, using reconstruction of 2D PIV.

II.METHODOLOGY

Our experimental model of the heart is represented by two chambers separated by a perforated wall between two half cylinders placed symmetricaly in opposition as shown on fig 1(a). The global cylinder diameter is 40mm. The upstream represents the left ventricle with the highest pressure in heart according to cardiac cycle. Downstream the orifice, the low pressure chamber is the left atrium. The device has been immersed in a water tank in order to minimise optical distortions. The physiological conditions have been provided by a pump governed by a synthetizer signal generator. A Doppler flow-meter give the time evolution of flow rate downstream of the pump. The blood is simulated by a glycerin-water mixing with a similar viscosity at 20°C. The velocities measurements have been made by PIV method, using silica particles seeded in the flow (15µm of mean diameter) illuminated with a laser light plane. The data have been acquired in 14 planes: 7 in (x,z) directions and 7 in (y,z) direction (as shown on fig.1(b).).



(a) Prolapsus Model (b) PIV Plans

Figure 1. : Experimental model

Each planes are separated by 5mm. The pump was adjusted to reproduce the flow rate of the left ventricle; so we have velocity fields at 0ms, 50ms, 100ms, 150ms, 200ms, 250ms, 300ms in the cardiac cycle (the systolic pic is near 250ms).

III.RESULTS

The fig 2. and fig 3. show velocities fields upstream and downstream the orifice (respectively right and left on the figure.), in 3 planes (the upper is in (y,z) direction and the two others in (x,z) direction with the second at 10mm of diameter). Fig 2. is at 100ms and the fig 3. at 200ms. On the fig 2. and fig 3., the upstream isovelocity surfaces don't have an hemispheric shape but look like a snail shell. Downstream the orifice, the fig 2. shows the beginning of systolic peak with an acceleration of the flow as shown clearly on the (y,z) plane. A separation in two branches can be visualized on fig 3. in (x,y) plane. This is the consequence of impact against the cylinder. With a maximum pressure drop of 180mmHg, during the cardiac cycle, the velocity values at the outlet of the orifice ranged from 3cm/s to 30cm/s.

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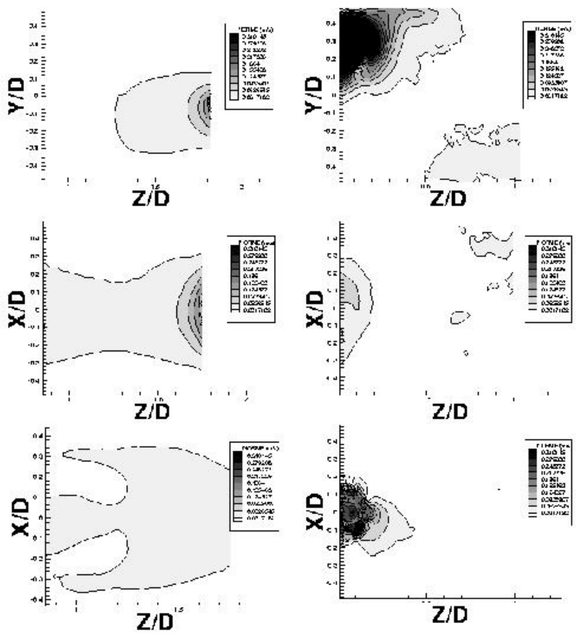

Figure 2 : Isovelocity curves in differents planes at t=100ms after the start of cardiac cycle; upstream on th left column, downstream on the right; The two fields on the top are in (y,z) direction and the two others in (x,z) directions.

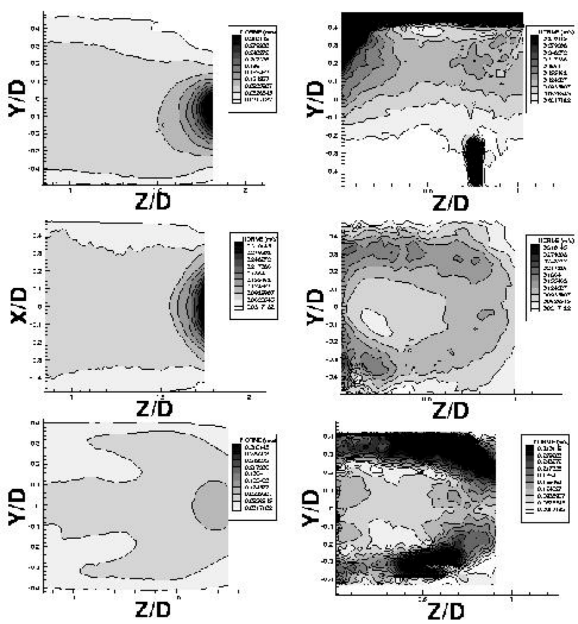

Figure 3 : Isovelocity curves in differents planes at t=200ms after the start of cardiac cycle; Upstream on the left column, Downstream on the right; The two fields on the top are in (y,z) direction and the two others in (x,z) directions.

IV.CONCLUSION

Despite the ultrasound characterization of flow in the convergent region, the calculation of flow rate by theses methods usually demonstrated a 30 to 40% underestimation due to the angle Doppler effect. Our 2D PIV in three-dimention study give more exact information of the flow behaviour. A comparison of the two methods can be useful to assess the magnitude of the Doppler distortion in the 3D estimation of vector velocity field. Perfect knowledge of flow distribution in this complex model is important in order to correct this miscalculation induced by the ultrasound methods and to propose correcting factors to enhance accuracy of regurgitant flow rate calculation in clinical setting.

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